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ON THE STUDY OF LEFT-HANDED COPLANAR WAVEGUIDE COUPLER ON FERRITE SUBSTRATE

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Abstract—This paper introduces a 3 dB tunable symmetric left handed coupled line coupler implemented on ferrite substrate. The proposed coupler is realized in LH coplanar waveguide configuration constructed using interdigital capacitors and meandered line inductors. The analytical analysis and the numerical verification of the proposed couple line coupler are presented. The full wave numerical simulation results for different DC magnetic bias indicate that a tunable left handed coupled line coupler propagation with transmission coefficient up to 3 dB and isolation level more than 25 dB over a wide bandwidth can be achieved.

1. INTRODUCTION

In the past few years, there has been a great interest in left handed materials (LHMs) i.e., materials whose both permittivity and permeability are negative, due to their unique properties that make them attractive to be used in many applications. The LHMs have been realized in different configurations either as a volume version or a planar version [1–4]. Recently the use of left-handed (LH) coplanar waveguides (CPW) in RF/microwave applications have been proposed and demonstrated experimentally, where different types of loading series capacitors and parallel inductors have been illustrated in realizing the left handed nature [5].

Ferrite medium substrate has tunable dispersive properties depending on the direction and value of the applied magnetic bias to the ferrite substrate [6]. Therefore, a tunable LH transmission line (TL) is expected on ferrite substrates which has been recently demonstrated in different planar configurations [7–10].

The different types of conventional microwave coupled line couplers have a trade off between bandwidth, coupling level, and structure implementation constraints. The novel properties of the LH TL can lead to novel performance of LH coupled line coupler [11]. Unlike to the conventional quarter wave coupled line coupler, the LH coupler can provide arbitrary high coupling level, even 0 dB, with relatively wide lines separation over a broad bandwidth. Also, it has high forward coupling at lower frequency without the need to increase the physical length which is the case in conventional one. The left handed coupled line couplers were introduced in microstrip configuration [12, 13] and using CPW configuration [14].

In this paper we will present a uniplanar and symmetric LH CPW coupled line coupler (CLC) on ferrite substrate. The individual LH CPW TLs were designed using planar meandered line segment wires as shunt meandered line inductors and series interdigital capacitors. The proposed coupler has the advantages of its compact size and high coupling level. Also, it has the capability of being tunable due to the effect of the ferrite substrate. Moreover, in comparison with ferrite microstrip configuration, the ferrite CPW one requires lower dc magnetic bias since it has much smaller demagnetization factor. The performance of the proposed coupler is explained analytically and verified numerically structure is presented.

2. THEORY

The layout diagram of the proposed LH CPW coupled line coupler over ferrite substrate is shown in Figure 1(a). The CPW coupled line coupler is designed using two identical LH transmission lines separated by a distance s_o. Each individual LH transmission line is designed using a CPW transmission line loaded periodically using a shunt meandered line inductor and series interdigital capacitor in two unit cell configurations.

The series load interdigital capacitor has six fingers. Two identical interdigital capacitors used at both the input and the output of the coupler are identical whereas the one between the two periodic cells has double length, t_a, and double air gap between the capacitor fingers and the periodic cell end, t_{ac}, compared to the dimensions of the two capacitors at both ends. Otherwise, all interdigital capacitors have the same finger width, W_c and separation, S_c. The shunt inductive load is formed by a meandered line inductor has only two meandered arms. The detailed dimensions of the loading elements are shown in Figures 1(b) and (c).

Extension legs of the two coupled line are added at each line at each port for the proper simulation of the real case of fabricated circuit. The dimensions of the CPW TL at each port of the proposed coupler are identical such that they represent a 50 ohm transmission line.

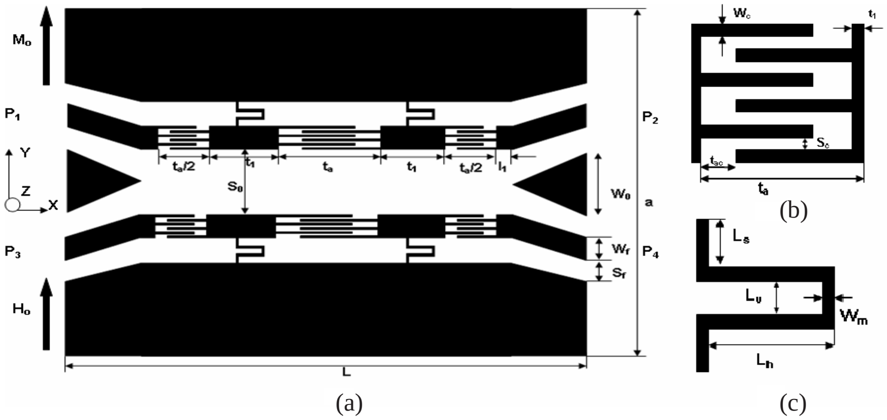

Figure 1. (a) The layout geometry of the ferrite LH CPW CLC, $a = 19.8\,\text{mm}$, $L = 10.32\,\text{mm}$, $W_0 = 6\,\text{mm}$, $t_a = 2.06\,\text{mm}$, $t_1 = 1.5\,\text{mm}$, $l_1 = 0.25\,\text{mm}$, $S_o = 2.5\,\text{mm}$, $S_f = 0.8\,\text{mm}$, $W_f = 1.3\,\text{mm}$, (b) the inter digital capacitor geometry $S_c = W_c = 0.1\,\text{mm}$, $t_{ac} = 0.4\,\text{mm}$, (c) the meandered line inductor geometry $W_m = 0.25\,\text{mm}$, $L_s = 0.25\,\text{mm}$, $L_v = 0.25\,\text{mm}$, $L_h = 0.5\,\text{mm}$.

The ferrite substrate has a relative permittivity of 15, height of $h = 1\,\text{mm}$. The magnetic properties of the ferrite substrate are a magnetic saturation, $M_o = 1780\,\text{Gauss}$ and a magnetic loss, $\Delta H_0 = 30\,\text{Gauss}$. An external DC magnetic field (H_o) is applied to the ferrite substrate in the shown direction in Figure 1(a) inducing an internal magnetic field which causes the ferrite substrate to have the saturation magnetization in the same direction.

The performance of the LH coupler can be explained using the coupled mode approach [11]. The coupled mode equations for the forward and backward modes along the two coupled lines can be given as

$$\frac{\partial a_1^+}{\partial z} = -j\beta a_1^+ + jC_{BW}a_1^- \tag{1}$$

$$\frac{\partial a_1^-}{\partial z} = +j\beta a_1^- - jC_{BW}a_1^+ \tag{2}$$

where β is the propagation constant of the individuals LH lines and can be obtained from [8]

$$\cos(\beta d) = 1 - \frac{1}{2}\omega^2 d^2 \left(\mu_0 \mu_f - \frac{1}{\omega^2 C d}\right)\left(\varepsilon_0 \varepsilon_f - \frac{1}{\omega^2 L d}\right) \tag{3}$$

where C_{BW} is the backward coupling coefficient that can be described as

$$C_{BW} = \omega \sqrt{\frac{\varepsilon_0 \varepsilon_f}{\mu_0 \mu_f}} L_m \tag{4}$$

and L is the shunt inductance, C is the series capacitance, L_m is the mutual inductance between the two coupled lines, ε_f is the ferrite relative permittivity, and μ_f is the ferrite equivalent relative permeability. Through this analysis, the propagation constant along the coupled lines can be obtained as

$$\beta_{I,II} = \sqrt{\beta^2 - C_{BW}^2} \tag{5}$$

From the above equations, it is clear that both the propagation constant of the forward and backward waves along the coupler and the coupling factor have a dispersive nature due the dispersive nature of the ferrite permeability. Therefore, it is expected to have a tunable LH coupler by varying the applied DC magnetic bias.

The optimum performance of the proposed CPW LH coupler is obtained through the parametric studies of the different circuit geometry parameters and the coupling performance for the different values of DC magnetic bias.

3. NUMERICAL RESULTS

The performance of the proposed CLC has been analyzed numerically using full wave simulation. The commercial software ANSOFT-HFSS is employed. For simplicity the applied DC magnetic field is assumed to be uniform in all studied cases. The numerical transmission characteristics of the proposed CPW ferrite LH coupler are simulated for different dc bias values of 1000, 1250, and 2000 Oe.

For the case of 1000 Oe, the resultant scattering parameters shown in Figure 2 show a backward coupler with an equal through and coupling level approximately equal to 5 dB and an isolation level up to 27 dB. The center frequency at which the reflection and the isolation level is minimum is 3.2 GHz with a bandwidth at which both the through and the coupled level changes by 2 dB is approximately 25%.

For the case of 1250 Oe, the simulated scattering parameters which are shown in Figure 3 shows also a backward coupler with

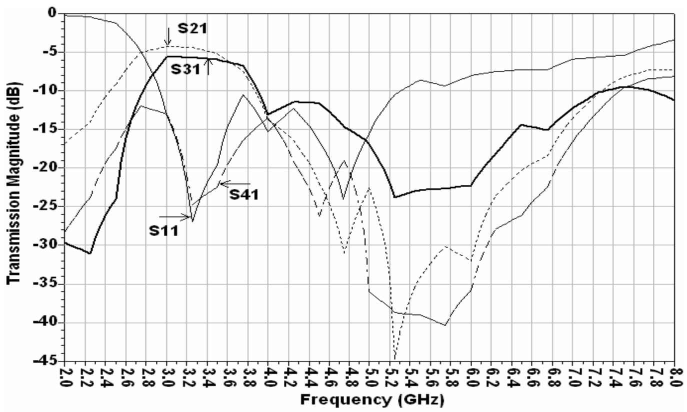

Figure 2. The full wave simulated magnitude of scattering parameters of the proposed coupler for $H_o = 1000\,\mathrm{Oe}$.

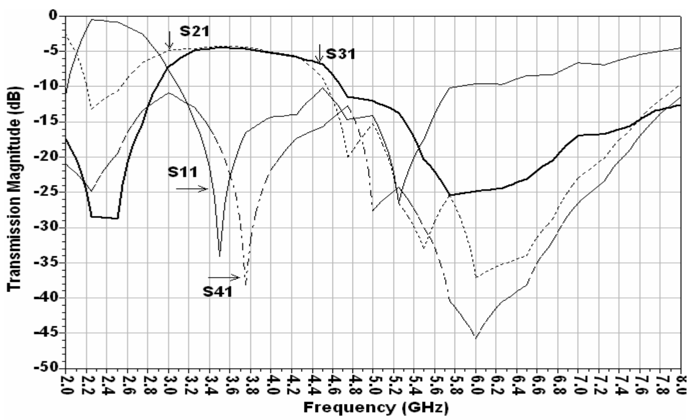

Figure 3. The full wave simulated magnitude of scattering parameters of the proposed coupler for $H_o = 1250\,\mathrm{Oe}$.

approximately 4 dB coupling and through level with an isolation level up to 40 dB. The centre frequency is observed to be shifted to 3.6 GHz while the coupler has a bandwidth equals 29%.

Finally, the last case of 2000 Oe dc bias, the simulated scattering parameters which are shown in Figure 4 shows a 3 dB backward coupler with isolation up to 27 dB. The centre frequency in this case is shifted again to 3.9 GHz where the bandwidth is 61%.

From the above results it is clear that the proposed LH coupler has tuning capability for both the centre frequency and the bandwidth.

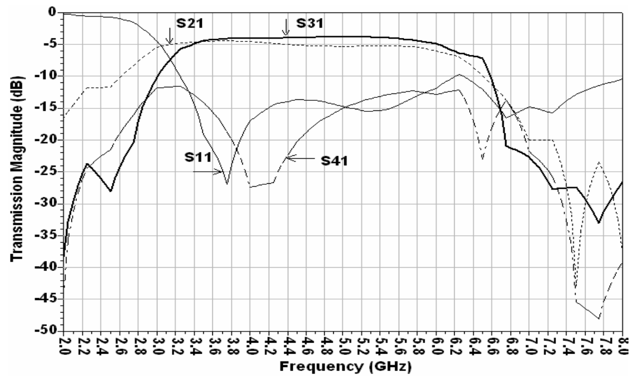

Figure 4. The full wave simulated magnitude of scattering parameters of the proposed coupler for $H_o = 2000\,\text{Oe}$.

4. CONCLUSIONS

A tunable LH CPW coupled line coupler over a ferrite substrate has been studied. The coupler was designed only using two identical LH TLs. The performance of the proposed coupler has been studied numerically through its scattering parameters. The results show tunable transmission characteristics by varying the DC magnetic bias with coupling level up to a 3 dB coupling factor and isolation level more than 25 dB over a wide bandwidth. The proposed ferrite CPW coupler has the advantage of its small size and its small demagnetization factor and hence it does not require high applied DC magnetic field compared to the microstrip configuration.

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